PALEOECOLOGY OF THE DELAWARE VALLEY REGION
PART I:
CAMBRIAN TO JURASSIC

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Introduction

This work is intended to be a guidebook for students, teachers, researchers, and advanced amateurs. The emphasis has been on presenting a comprehensive view of the evolutionary paleoecology of the Delaware Valley region. The definition of the Delaware Valley region is interpreted loosely here, in order to present as complete a sequence of the geological record as possible. The happy fact is that a wide variety of fossiliferous exposures exist within several hours drive of Philadelphia. This affords the student of paleontology the opportunity to investigate the development of ancient ecosystems through most of Phanerozoic time.

In Part I, locality information is given for the Cambrian through Jurassic. Beyond providing lists of species or site descriptions, an attempt has been made to determine environmental conditions and relate them to larger processes such as plate tectonic interactions. Thus, the first section of the work can be seen as the record of the response of ancient life in one geographic area to a cycle of continental coalescence, fusion, and initial rifting and separation. Part II will deal with the paleoecology of the Upper Cretaceous and Cenozoic Coastal Plain deposits.

This work cannot be definitive in terms of listing every locality in the region. Sites come and go with the vagaries of development and the whims of private property owners. That brings up the topic of fossil-hunting etiquette. A number of the localities listed here are on private property; some, such as the famous "Centerfield Reef" exposure, are no longer available for collecting because the owners are afraid of insurance risks. Before entering private property, always ask permission first. If it is obtained, one should always act in a responsible manner; do not endanger yourself, keep unnecessary digging to a minimum, do not litter, be courteous, and do not over-collect. Others will come after you; don't spoil a site for them.

Cambrian

The Paleozoic in the Delaware Valley region started out with deposition of clastic material from the North American craton to the west. This coarse sediment formed a belt of quartzite which is known as the Chickies Formation in Pennsylvania and the Hardyston Formation in New Jersey.

This set the stage for carbonate deposition for the rest of the Cambrian in this region. Limestones, dolomites, and occasional shale beds dominate the sequence right up through the middle Ordovician. In New Jersey, these carbonate beds are collectively known as the Kittatiny Limestones; in Pennsylvania, the Kittatiny Group is subdivided into the Kinzers, Leithsville, Limeport, and Allentown Formations. Cambrian sequences are thinner in the area covered by this work than the thicker sections to the north, in New York and Vermont, and in the Appalachians to the southwest. Additional difficulties have arisen from the varied stratigraphic nomenclature applied to closely related rock units arising from problems of poor exposure, few fossils, moderate deformation, eastward metamorphism, and faulting (Palmer, 1971).

The shallow, limey seas of Cambrian time provided an excellent habitat for the reef-building algae Cryptozoon and related types. Other important life-forms of this time include the trilobites, the dominant animals of the seas, and the inarticulate brachiopods such as Lingulella. Worms were abundant, if we can judge by the widespread burrows found in Lower Cambrian rocks. The fine-grained Burgess Shale of Middle Cambrian time in British Columbia reveals a varied fauna including jellyfish, sea cucumbers, sponges, arthropods, and many different kinds of annelids.

1. Mount Misery, Valley Forge, Chester County, Pennsylvania

The oldest fossils in the area occur at this historic park.

Lithology -- The Chickies Quartzite (= Hardyston Formation of New Jersey) is a white to pink crystalline very hard rock that weathers to gray. Originally deposited as a sandstone, subsequent folding and pressure have metamorphosed it to a quartzite. Locally, outcrops of milky quartz occur. Black mineral specks in the rock are tourmaline.

Fossils -- The only trace of ancient life found here is the worm tube Skolithos linearis. This fossil is found in the form of a series of parallel lines in the rock, each line an individual burrow. They are one-eighth to one-fourth of an inch wide; this writer's longest specimen measures six inches. They are generally in slight relief on the rock surface, and are usually a darker brown or darker gray than the matrix. The Chickies was laid down as a clastic apron along the fringes of the shallow Cambrian sea; ripple marks and mudcracks have been observed in the quartzite, indicating a shallow, perhaps intertidal, nearshore environment. Skolithos has also been found at Diamond Rock in Chester County, Pa.; some fragmentary Olenellus have been found at Buckingham Mountain in Bucks County in Chickies exposures in old quarries (Richards, 1956, p. 28-29). Skolithos and allied forms must have been very common; Dunbar (1960, p. 121) reports burrows of this sort from Tennessee, Virginia, New York, Wisconsin, and Sweden.

Age -- On the basis of the Olenellid trilobites, the Chickies is assigned a Lower Cambrian age (Waucoban).

2. Fruitville Quarry, Lancaster, Lancaster County, Pennsylvania

Lithology -- Shaly micaceous siltstone.

Fossils -- The old quarry near the Fruitville Pike is famous for its Cambrian fauna. The trilobite Olenellus vermontanus is found at this site; it is a protoparian with a characteristic telson (or spike) protruding from the pygidium. The conical molds of the enigmatic Salterella (Hyolithes) may also be collected; the taxonomic category of this fossil is still uncertain. There are also some imprints of inarticulate brachiopods, although these are less common. Access to this locality is controlled by the Department of Geology at Franklin and Marshall College in Lancaster. Permission to visit the quarry must be obtained from the Department of Geology. Collecting specimens is frowned upon because of the unique nature of the fauna. However, a visit to observe the quarry may be arranged and should prove rewarding; fragmentary remains of trilobites can be seen in the broken rocks of the talus slope. Echinoderms have also been reported from the quarry.

Age -- Kinzers Limestone, Lower Cambrian (Waucoban).

3. Buckingham, Bucks County, Pennsylvania

Lithology -- Dark grayish to black dolomite with carbonaceous layers and black chert nodules. The rock weathers to a lighter buff or whitish shade. Strike N 70° E, dip 34° NW.

Fossils -- While no large-scale organic forms are found, evidence of ancient life is abundant. The carbon layers may be metamorphosed organic material, possibly plants. The chert nodules were formed as silica precipitated around siliceous sponge remains. Oolite layers are also present at this site; oolites are small rounded bodies, pisolitic in texture, that accrete around wave-worn fossil shell or fecal pellets. There are some excellent ripple marks preserved in the rocks here; along with the oolites, which probably formed as wave and tidal action swept fragments back and forth and rounded them off, the ripple marks indicate an intertidal environment.

Age -- Leithsville Formation, Middle Cambrian.

4. Limeport, Bucks County, Pennsylvania

Lithology -- Red shaly limestone with interbedded grayish-black limestone layers. Rock weathers to a light brown.

Fossils -- Some stromatolites have been found at this locality, but the site also contains, in a few darker limestone beds near the bottom of the section, a fauna of trilobites. The inarticulate brachiopod Lingulella is also found here, although it is less frequent than the trilobite remains. The trilobites typically occur as separated cephalons and pygidia, with an occasional thoracic segment attached. The fragments are small and a hand lens is useful in identifying specimens; the trilobite pieces are found in thin layers within the darker beds, and are usually slightly darker than the gray-black matrix. Richards (1956, p. 36) reports the trilobite genera Pemphigapsis, Welleraspis, Talbotina, Lonchocephalus, Coosia, and Genevievella from this site.

Age -- Limeport Formation (= Conococheague Formation), Upper Cambrian (Dresbachian).

5. Lahaska, Bucks County, Pennsylvania (Buckingham Valley)

Lithology -- Alternating gray limestone and dolomite with some shale beds. Strike N 32° E, dip 22° NW.

Fossils -- Large curved stromatolite structures are evident in the old quarry near Solebury Church. The warm, limey nearshore and intertidal environments of the Upper Cambrian fostered the growth of extensive calcareous algal colonies. White the actual remains of the reef-building marine plants are not present, their "heads" are preserved as laminated curved or domed structures in the rock; these are called stromatolites. The folds appear as alternations of limestone and dolomite, sometimes attaining a width of three feet across at this locality. *Cryptozoon*, as some forms have been called, formed mats on the shallow bottom which trapped sand grains; as the colony was buried, it grew upward, forming a dome-like structure. Stromatolites exhibit a wide variety of growth patterns in response to differing environmental conditions, so taxonomic classification is difficult. At this site one can observe small channels preserved in the rock where stromatolite structures are depressed; there is also mudcrack breccia showing where an area was above water long enough to dry out. These are indications of an intertidal environment; and indeed there are analogous laminated algal masses forming today on intertidal mud flats and semi-marine shallow waters in Florida, the Bahamas, and Australia. Stromatolite structures dating back to 3.5 billion years have been found in Archeozoic rocks of western Australia; these bacterial stromatolites are the oldest evidence of life so far known.

Age -- Limeport Formation, Upper Cambrian.

6. Carpentersville, Warren County, New Jersey

Lithology -- Whitish-gray limestone interbedded with darker gray layers of dolomite.

Fossils -- Here again the stromatolites are found in conspicuous outcrops north of town in old quarries and gravel pits along the Delaware River. The darker layers are dolomite, which tends to be more resistant; lighter layers are limestone. Other areas in New Jersey where stromatolites have been found are Stillwater (Yolton, 1965, p. 33) and Finesville (Richards, 1956, p. 36).

Age -- Kittatiny Limestone, Upper Cambrian.

Ordovician

Limestone deposition continued without any clear erosional break across the Cambrian-Ordovician boundary. For this reason the uppermost portion of the Kittatiny Limestones, the Beekmantown Formation, is Ordovician in age but resembles the older beds below it; the formation was deposited in the same shallow, clear sea as the Upper Cambrian strata. Fossils are rare in the Beekmantown but clearly date it as Lower Ordovician. In Maryland, these beds are thicker and more easily subdivided; here, a fauna of sponges, corals, brachiopods, gastropods, cephalopods, arthropods, and echinoderms has been found (Sando, 1957). In some horizons of the Beekmantown in the Delaware Valley area, stromatolites and oolites occur.

The sea retreated from this area after the deposition of the Beekmantown Formation. The top of this unit shows evidence of erosion, and in some places hundreds of feet of this rock were removed (Lewis and Kummel, 1940, p. 73). The next beds are shales, indicating marine conditions with sediment influx from the east. The so-called Chazy shales contain graptolites, colonial relatives of the vertebrates, in exposures near Clinton and Jutland, in New Jersey (Lewis and Kummel, 1940). The limestones of the succeeding Jacksonburg Formation show a return to clear and shallow waters; shales toward the top, however, suggest increasing muddiness from sediment influx caused by the beginnings of uplift. This orogenic activity culminated later in the period, when the Martinsburg Slate was deposited. The Martinsburg was originally a shale that was subsequently metamorphosed; the materials for the shale were probably derived from the east during the Taconic Orogeny, when large overthrusts developed in western New England.

Many important forms of life first flourished during the Ordovician. While their origins were in the Cambrian, such groups as the bryozoa, the bivalves, corals, and echinoderms became abundant in this period. The trilobites continued to diversify, and the largest individuals of the class lived at this time. The articulate brachiopods predominated over the inarticulates. Giant cephalopods up to fifteen feet long swam in the seas. The traces of the first vertebrates, plates from a primitive armored fish, have been found in Middle Ordovician rocks near Canyon City, Colorado.

7. Jacksonburg, Warren County, New Jersey

Lithology -- Very fossiliferous dark gray shaly limestone.

Fossils -- The outcrop at the top of the cliffs northwest of the town of Jacksonburg reveals an abundantly fossiliferous stratum that is the first good example of a diverse lower Paleozoic marine community in this region. The most commonly found fossils are calcareous impressions of brachiopods, including Rafinesquina alternata, Strophomena conradi, Dalmanella rogata, and several other genera of orthid and strophomenid types; the cup coral Streptelasma corniculum; and numerous crinoid columnals. In addition, Miller (1937) has reported the trilobites Calliops, Prasopora, Dalmanites, and Bumastus, as well as the gastropods Holopea excelsa and Hormotoma gracilis from this locality.

The diversity of this fauna is not without its paleoecological significance. The explosive evolution of many new organisms produced, by the Middle Ordovician, a new kind of ecospace, the reef. Trapping detritus within its interstices and building upon the accumulated skeletal material of antecedent organisms, the reef provided a heterogeneous environment with a variety of niches. To be sure, algae and the now-extinct archaeocyathids had built reef structures in the Cambrian, but the more advanced forms, the corals, crinoids, brachiopods, and bryozoa became better adapted to warm, shallow marine environments and so created the more familiar type of reef ecology. Apparently, such an environment is represented at this site.

Age -- Jacksonburg Limestone, Middle Ordovician.

8. Swatara Gap, Lebanon County, Pennsylvania

Lithology -- Dark gray shale.

Fossils -- Most of the specimens found at this old quarry are molds; frequently they are stained orange. The most common fossils here are pieces of the trilobite *Cryptolithus*; usually a portion of the distinctive cephalon with its long genal spines and dimpled cephalic border is found, but bits of thorax and pygidium are common. A whole specimen is somewhat rarer. *Flexicalymene* is a larger trilobite, sometimes found rolled up; it is far less common than the "little groveler," *Cryptolithus*. Two rare trilobites also found here are *Bumastus* and *Isotelus*; the latter genus produced the giant among the group, *I. gigas*, up to two feet long. Several strophomenid brachiopods (*Rafinesquina*, *Dalmanella*, *Sowerbyella*) are present. Mollusks include many specimens of the nautiloid *Michelinoceras*, as well as a gastropod (*Sinuites*) and a pelecypod (*Lyrodesma*). Crinoid columnals and stalk sections are common; one of the most unusual fossils found here is the brittle star *Hallaster*. Harder to identify but also unusual are the graptolite specimens; these colonial protochordates floated about the Ordovician oceans, and their remains are often found in the dark shales deposited in deeper waters.

Indeed, the assemblage seems to be one more characteristic of eugeosynclinal conditions, in contrast to the miogeosynclinal Jacksonburg fauna. This deeper-water assemblage probably lived in poorly-oxygenated muddier conditions within a trough that was being rapidly filled in by sediments from a tectonic source area to the east. The cause of the sedimentation was probably uplift associated with the Taconic Orogeny; initial subduction of a proto-Atlantic Ocean may have produced a line of volcanic islands, similar to today's Pacific archipelagoes, behind the subducting trench. While the fauna at Swatara Gap is more typical of greater depth, it is clear that the environment was not as deep as preceding greywacke deposits in the Martinsburg would indicate. The unconformable contact between the Martinsburg and the overlying Shwangunk Conglomerate is observable just above the old quarry, across Interstate 78. The shallower aspect may have resulted as the Taconic Orogeny uplifted the region; the unconformity represents a period of erosion between the Ordovician and the Silurian.

Age. -- Upper Martinsburg Formation, middle Upper Ordovician (Pulaskian).

Silurian

As indicated above, the Silurian started out with the area uplifted and largely mountainous, while the sea had retreated to the west. Gradually, the Taconic ranges were leveled. The sediment from this erosion was composed of coarse sand and pebbles; this material was probably laid down as a complex of braided streams and estuaries, and eventually buried, compacted, and folded to form the Schwangunk Conglomerate. This formation is the first major ridge before the Appalachian Valley and Ridge province. The hard conglomerate forms an almost continuous set of ridges that can be traced from near New Paltz, N.Y., through Kittatiny Ridge in New Jersey and Blue Mountain into central Pennsylvania. While most of the conglomerate was deposited in a steep-gradient freshwater environment, some of the shale beds within the formation probably represent estuarine conditions. Within these beds, specimens of eurypterids and dipleurozoa (extinct coelenterates) have been found, notably at Delaware Water Gap, Pa. (Johnson and Fox, 1968). Some problematic burrows of the sort known as *Arthrophycus* have also been found in the Shwangunk.

The next stratigraphic unit is known as the High Falls Formation in New Jersey and as the Bloomsburg Red Beds in Pennsylvania. The formation usually occupies the northwestern slopes of the Kittatiny Ridge and Blue Mountain. Composed primarily of red and green shales, it was laid down in a low-gradient coastal plain by meandering streams. Except for a few rare fish fossils and some obscure burrows, the formation is barren.

By the Upper Silurian, continuous erosion had reduced the landscape to a flat plain and the sea invaded the region once more. A series of silty carbonate beds was laid down at this time, representing a tidal flat-barrier bar complex similar to the environment seen along the New Jersey shore today.

Silurian life was not very much different in its major aspects from the life of the Ordovician. Some forms, such as the brachiopods and the crinoids, continued to flourish. Other previously abundant types, such as the graptolites, began to decline. Perhaps the most dramatic element of the Silurian fauna was the eurypterids. Some of these large arthropods reached lengths of nine feet; they lived in estuaries and streams. A major innovation in the plant kingdom was the colonization of land by vascular plants. Fish fossils are generally rare, and represent primitive armored ostracoderms and placoderms.

9. State Fish and Game Land, Walpack Center, Sussex County, New Jersey

Lithology -- Gray limey sandstone with rust-brown beds interlayered.

Fossils -- The exposure is on the east bank of the Big Flatbrook, at water level north of the bridge. It is difficult to locate and may be submerged during times of high stream flow. The fossils are mostly found in the oxidized brown layers. Nearer the stream bed is a harder, more massive rock containing numerous crinoid columnals. In the more friable rust-colored fossiliferous beds further up from stream level, there are many brachiopods (specimens of *Chonetes jerseyensis* are most frequent), coral (*Favosites*), and bryozoa of the encrusting *Monotrypa* type. Fragmentary snail remains are also present. The environment indicated is shallow water, relatively clear, with beaches nearby contributing sand.

Age -- Decker Formation, Upper Silurian.

10. Flatbrookville, Sussex County, New Jersey

Lithology -- Reddish brown sandstone.

Fossils -- Again the fossils are concentrated in thin biostromal layers. The Silurian deposits here are characterized by the brachiopod *Atrypa reticularis*, an early member of the spiriferid family. *Chonetes jerseyensis* is also present, and coral and crinoids are found in the thin reddish layers. Toward the top of the Silurian, there are beds containing fossil ripple marks. These, combined with the concentration of fossils in thin layers, indicate a beach-intertidal environment. Above the Silurian are gray calcareous sandstones which are probably

Lower Devonian in age; these beds also yield specimens of brachiopods and coral, as well as an occasional piece of trilobite. The sea in which the Silurian fossils lived extended to the south and east; forms identical with those found at Walpack Center and Flatbrookville have been reported from limestones and shales near Petersburg, Newfoundland, and the Green Pond Mountain area in New Jersey (Lewis and Kummel, 1940, p. 85).

Age -- Decker Formation, Upper Silurian (Cayugan).

11. Walpack Center, Sussex County, New Jersey

Lithology -- Hard, dark limestone that weathers to a buff color, with interbedded thin, sandy, brown layers, and cherty beds.

Fossils -- The exposure occurs in a road cut on the Flatbrook Road four miles southwest of Walpack Center. Once more, the fossils are found concentrated in thin (no more than two inches thick) biostromal beds that can be traced along the outcrop. The sandy brown layers are the fossiliferous beds; these contain an abundant brachiopod fauna. Corals and a few crinoid columnals are also found in these beds. The brachiopods are mostly of the spiriferid type. This group originated in the Middle Silurian, although close relatives (such as Atrypa) had been around since the Middle Ordovician. The suborder Spiriferacea is characterized by shells with a long hinge line, strong radial ribs, a prominent mid-fold, and a definite beak. They became very profuse during the Devonian. This points up a problem with the stratigraphy of the Silurian-Devonian contact in this region. While the break between the two periods is well established in Europe, the Cayugan stage seems to include the Silurian-Devonian boundary, and separating the two systems is not as easy in this part of North America. The two formations of the uppermost Silurian, the Rondout and Manlius, have been reassigned by some workers in New York to the Lower Devonian. A similar problem exists with the Keyser Formation of south-central Pennsylvania (exposed near Kistler, Pa.); previously assigned to the Upper Silurian, it may bridge the Silurian-Devonian boundary and may be at least in part Lower Devonian. Tentatively, the exposure here is regarded as Upper Silurian, following the older nomenclature.

Age -- Manlius Formation, Upper Silurian (Lower Devonian?)

12. Nearpass Quarry, Montague, Sussex County, New Jersey

Lithology -- A series of light to dark limestones with interbedded shales.

Fossils -- The old Nearpass Quarry section exposed a complete sequence of Upper Silurian and Lower Devonian formations. Although the bottom portion of the section has now been largely covered due to slumping, it is still possible to see the lower layers by means of trenching. The Upper Silurian here is represented by the Bossardville Limestone, the Decker Formation, the Rondout Formation, and the Manlius Formation. All these strata are more or less fossiliferous, with the best hunting in the Decker (brachiopods, crinoids, coral, and ostracods) and the Manlius (brachiopods, ostracods, Tentaculites, stromatoporoids); the Bossardville and Rondout contain ostracods. Above the

Silurian formations, the Lower Devonian Coeymans Formation is present and abundantly fossiliferous. The old quarry is in the southeast face of Walpack Ridge, where many outcrops of not only the Upper Silurian but also the Lower Devonian formations occur naturally as ledges, or in man-made road cuts.

Age -- Upper Silurian (Cayugan) and Lower Devonian (Helderbergian).

Devonian

The generally transgressive cycle that started in the Silurian continued into the Lower Devonian. The tidal flat and barrier beach deposits of the Upper Silurian give way to neritic, nearshore marine beds, although regressive phases within the trend toward deepening water are also present (e.g., the Stormville Member of the Coeymans Formation). The shoreline continued to fluctuate through Oriskany deposition, but by late Lower Devonian deeper-water deposits were firmly established and the neritic regime seems to have been the dominant environment in the Appalachian area through the Middle Devonian.

By the Middle Devonian, evidence of uplift began to manifest itself by the deposition of sandstones, shales, and clastic limestones. Mud and sand were being contributed to the marine basin by areas of higher relief. In the late Devonian, the pace of uplift accelerated; this episode is known as the Acadian orogeny, probably associated with the further closure of the proto-Atlantic Ocean, also known as Iapetus. The compressional force may have been provided by a volcanic island arc associated with a subduction zone, or it may have involved the welding of part of northern Europe to the North American coast. At any rate, the uplifted area produced a series of great deltas now known as the Catskill Redbeds. These are largely sandstone and conglomerate, and they are prominent mountain-formers, making up the Catskill Front and part of the Poconos. The sea retreated inland to the west and marine deposition ceased in this region.

Some important evolutionary developments occurred in the Devonian. Many of the invertebrate forms flourished in the warm shallow seas of this period; corals, bryozoa, and crinoids formed extensive reefs, and brachiopods were at their most abundant. The trilobites, however, were beginning their long decline. Pelecypods became widespread for the first time, and the first ammonites appeared. Fish became profuse, and sharks and modern bony fish evolved during the Devonian. From one stock of fish, the crossopterygians, the amphibians arose. Specimens of Ichthyostega from the Upper Devonian of Greenland are the first land vertebrates of record. Forests and scale-trees and ferns had prepared the way for these first air-breathers.

13. Montague, Sussex County, New Jersey (Genarelli property, Birdhaven Farm)

Lithology -- Medium-light gray crystalline crinoidal limestone.

Fossils -- Situated at the top of Walpack Ridge, the Genarelli farm is private property, and permission must be obtained before entering. On the east slope of the ridge, on an escarpment below the exposure of dark cherty limestone, the crinoidal limestone of the Coeymans Formation is exposed. In addition to the numerous crinoid columnals, the most common fossil here is the brachiopod Gypidula coeymanensis. This is part of a reef deposit; corals are also present here. The limestone was formed in shallow water, probably near barrier beach islands, as sandstone facies elsewhere in this formation indicate.

Age -- Coeymans Formation, Devonian.

14. Montague, Sussex County, New Jersey (Deckertown Turnpike)

Lithology -- Light pink to light gray limestone, weathering to buff.

Fossils -- This exposure is part of the bioherm (reef) facies. Large masses of honeycomb corals are present here; cup corals are also present. Many large, pinkish crinoid columnals can be found weathered out of the matrix. The fossils again represent a shallow benthonic environment. Stromatoporoids are also found here.

Age -- Coeymans Formation, Helderberg Group, Lower Devonian.

15. Peter's Valley, Sussex County, New Jersey

Lithology -- Light gray crystalline limestone.

Fossils -- Abundant crinoids, many brachiopods (*Stropheodonta*), and corals. Similar fossils are found above the Silurian deposits at Flatbrookville (see locality 10).

Age -- Coeymans Formation, Helderberg Group, Lower Devonian.

16. Montague, Sussex County, New Jersey

Lithology -- Gray fossiliferous calcareous shale.

Fossils -- Just east of Clove Road on the Deckertown Turnpike, a low shelf of gray shale is exposed on the south side of the road. This outcrop yields numerous brachiopods; the most common varieties are *Leptaena rhomboidalis* and *Eospirifer macropleurus*. As mentioned above, brachiopods were extremely abundant during the Devonian, and during most of the Paleozoic they dominated the sessile benthonic niche later taken over by the bivalves. Sometimes they formed extensive, densely packed communities, particularly on soft substrates where the brachiopods had ample food in the form of suspended organic particles in the water above the bottom. This type of environment would require deeper quiet waters, and this formation is regarded as representing a period of greater submergence (Epstein *in* Subitzky, 1969, p. 155).

Age -- New Scotland Formation, Helderberg Group, Lower Devonian.

17. "Trilobite Ridge," Montague, Sussex County, New Jersey

Lithology -- Dark gray siliceous limestone.

Fossils -- On the southeast slope of Walpack Ridge, a hard stratum forms a prominent acclivity that is very fossiliferous. This is the "Trilobite Ridge" or "trilobite beds" of many authors, so called because pieces of the spar-tailed trilobite *Dalmanites dentatus* are especially abundant here. Usually, just heads and tails (cephalons and pygidia) are found, sometimes associated with a few thoracic segments; an entire specimen is difficult to come by. This is probably because the bits and pieces of trilobite are exuviae (molted shells) shed as the animals grew. They may have been concentrated in this deposit by currents or wave action. Mollusks include the pelecypod Actinopteris textilis, the gastropod Loxonema, and the nautiloid Michelinoceras. Coelenterates are represented by large circular colonies of the tabulate coral Emmonsia tuberosa. Brachiopods collected at this site are Acrospirifer murchisoni, Leptostrophia magnifica, and members of the genera Chonetes and Atrypa. The siliceous nature of the limestone indicates a decrease in the depth of the sea in this area.

Age -- Oriskany Formation, Lower Devonian (Oriskanian).

18. Layton, Sussex County, New Jersey

Lithology -- Dark cherty, shaly limestone.

Fossils -- Some of the layers along Route S21 near the crest of Walpack Ridge contain many spiriferid brachiopods and some crinoid columnals. This formation probably indicates a return to deeper neritic deposition.

Age -- Esopus Formation, Onondaga Group, Middle Devonian.

19. Rockville, Dauphin County, Pennsylvania

Lithology -- Light to medium gray shaly sandstone.

Fossils -- Along the north slope of Blue Mountain on the east bank of the Susquehanna River, just north of Harrisburg, exposures along road cuts reveal fossiliferous Devonian rocks. The exposures are not as good as the old quarries that used to occupy the area. An extensive fauna came from this area, including many varieties of brachiopods (Mediospirifer audaculcus, Camarotoechia congregata, Tropidoleptus carinatus, Delthyris sculptilis, Protoleptostrophia perplana, Athyris spiriferoides, and many other species). Crinoid columnals are common in some layers. Some nicely preserved specimens of the bryozoan Fenestella can be found throughout much of the exposed sequence. Pelecypods are frequently present; the abundant forms are Actinoptera decussata, Paleoneilo muta, Cornellites flabella, and Modiomorpha concentrica. Trilobites found here are Phacops rana, Greenops boothi, and Trimerus dekayi. Corals are present but rare. The sandy nature of this stratum indicates deposition in a nearshore environment (Hoskins, 1969, p. 65).

Age -- Montebello Member, Mahantango Formation, Hamilton Group, Middle Devonian (Erian).

20. Deer Lake, Schuylkill County, Pennsylvania

Lithology -- Medium gray silty, sandy shale.

Fossils -- There are several separate pits along Highway 61, each with its own distinct fauna. The first exposure is in the pit nearest to the intersection of Route 895 with Route 61. This portion of the outcrop has more pelecypods (Liopteria, Nuculites, Orthonota, Nucula, Paleoneilo, Modiomorpha, Aviculopecten) and an abundant brachiopod fauna (Mucrospirifer, Mediospirifer, Chonetes). Crinoid columnals are plentiful, and there are bryozoa and corals as well. There are a few pieces of cephalopod (Michelinoceras) and a few gastropods in the front pit. This is the best area to find specimens of the large trilobite Trimerus dekayi (up to six inches long), although Phacops rana and Greenops boothi are also found here. The rock is more massive and sandy, unlike the back pit, which exposes a more shaly facies. This second quarry, to the west and away from the road about a quarter of a mile, is characterized by entire specimens weathered out of the shale virtually intact. Here, complete enrolled Phacops specimens are more common, frequently with the compound eyes preserved in fine detail. Greenops is also present. Entire clams are abundant, and snails (Platystoma, Platyceras) are often found. There is also some bryozoa, and brachiopods are abundant. A third pit further to the north on Route 61 yields more examples of the nautiloid Michelinoceras, as well as Greenops and various brachiopods (Mucrospirifer, Chonetes). While the three exposures share many species in common, it is the relative abundance of one facet of the fauna that distinguishes each pit from its neighbors. This is the well-known Mahantango biostrome and as we shall see it stretches all the way from south-central Pennsylvania northeast into New York. Within the biostrome there are zones typified by certain faunal assemblages, probably reflecting changing environmental conditions. The front pit may represent shallower water with a sandy substrate; the back pit may indicate deeper water with a muddier bottom. The third pit may represent even deeper seas because of the relative abundance of the neritic Michelinoceras. The variation in ecological parameters is related to tectonic activity, which controlled depth, sediment influx, substrate and turbidity in the marine basin.

Age -- Mahantango Formation, Hamilton Group, Middle Devonian (Erian).

21. Beltzville Lake, Carbon County, Pennsylvania

Lithology -- Light gray shale with reddish layers.

Fossils -- Years ago an old quarry near Lehighton exposed the pelecypod zone, and many fine specimens were found at this site. The area was inundated after the Beltzville Dam was built and that locality is now under water. The Army Corps of Engineers, however, maintains a smaller exposure on the north side of the lake at Pine Run Cove. This is another example of the Mahantango biostrome, with its familiar fauna. Fossils seem to be more common in the more massive rocks, although the easily fissile shale layers also yield specimens. Clams, crinoid columnals, bryozoa (Fenestella), brachiopods (Mucrospirifer), and trilobites (Phacops rana) are all present. Again a warm, shallow near-shore environment is indicated.

Age -- Mahantango Formation, Hamilton Group, Middle Devonian (Erian).

22. Little Gap, Carbon County, Pennsylvania

Lithology -- Medium gray to grayish brown shale.

Fossils -- Outcrops on the road west of Little Gap once more reveal the Mahantango biostrome. Crinoid columnals, brachiopods (Mediospirifer), and bryozoa (Fenestella) are easily found. In addition, Hoskins (1969, p. 57) reports an extensive coral fauna, including Coenites, Trachypora, Heliophyllum, Heterophrentis, Zonophyllum.

Age -- Mahantango Formation, Hamilton Group, Middle Devonian (Erian).

23. "Centerfield Reef," Stroudsburg, Monroe County, Pennsylvania

Lithology -- Medium to dark gray calcareous shale.

Fossils -- While not actually a true reef or bioherm (a mounded structure), the biostrome at Stroudsburg yields a wealth of rugose and tabulate corals. Most common are the cup corals (*Heliophyllum* and related forms) which grew upward as the mud was deposited, their pointed ends in the substrate. Tabulate or honeycomb corals are also frequently found here, usually *Favosites* and *Coenites*. Both rugose and tabulate corals did not build reefs because they could only cement themselves weakly to the bottom; thus, they could not stand up to the high-energy environment of a reef-top ecology where wave disturbance would have dislodged them. Instead, they favored deeper, quieter waters where mudstones were deposited. Still, the Rugosa and Tabulata became very diverse during the Devonian, and they helped to create an ecological framework that was favorable to many other animals. Among the benthos that flourished at this locality were the brachiopods; many genera are reported from this site, but the most prominent forms are the spiriferids. In particular, the genus *Mucrospirifer* is commonly found here. *M. mucronatus* represents the extreme development of this group's characteristic features; it is strongly ribbed, with the hinge line extended by long "wings," and a conspicuous sulcus is in evidence in the middle of the pedicle valve with a corresponding fold in the brachial valve. Also quite common are specimens of the bryozoan *Fenestella*.

Perhaps the most remarkable specimens to be found at this spot are the frequently well-preserved *Phacops rana*. The trilobite's compound eyes are often intact, and if found on a large cephalon, can be clearly seen. *P. rana* is usually discovered in the coiled-up posture if the specimen is complete, although bits and pieces (especially pygidia) are more common. Mollusks include snails and clams; the pelecypods appear to be more common in the lower part of the exposure which yields excellent examples of *Actinoptera*. The clams may have been more prevalent when substrate conditions were sandier. Of course, there are many crinoid columnals here.

Age -- Mahantango Formation, Hamilton Group, Middle Devonian.

24. Dingman's Ferry, Pike County, Pennsylvania

Lithology -- Gray silty shale.

Fossils -- The shale pits at the base of the cliff overlooking the Delaware River along Route 209 provide excellent collecting in the Mahantango Formation. Large specimens of *Mediospirifer* weathered out of the rock are available here. Also notable are the many pieces of *Phacops rana*, with excellent cephalons showing the compound eye structure. Thoracic segments and cephalons of the larger trilobite *Trimerus* are easily located. Pieces of coral, bryozoa (*Fenestella*), and crinoid columnals are common. Mollusks include the gastropod *Tropidodiscus*, pelecypods (*Actinoptera*, *Orthonota*), and the nautiloid *Michelinoceras*. The rock here is more sandy, indicating an environment closer to the shore, perhaps during a period of time when tectonically controlled sediment influx was greater.

Age -- Mahantango Formation, Hamilton Group, Middle Devonian.

Carboniferous (Mississippian and Pennsylvanian)

In Europe, the strata above the Devonian and below the Permian are regarded as one system; in America, they have been subdivided into two periods, the Mississippian and Pennsylvanian. The Acadian orogeny at the end of the Devonian created highlands in the Delaware Valley region and marine deposition in the area ceased. Pulses of tectonic activity, probably connected with the closing of the proto-Atlantic ocean, continued through the Carboniferous. Hence, the deposits of Mississippian and Pennsylvanian age are largely representative of terrestrial and aquatic environments. Large amounts of sediments eroded from the Carboniferous highlands were deposited in swampy deltas that sloped westward from the mountains. Farther to the west, widespread limestones of Mississippian age exposed in the mid-western states reveal an abundant marine fauna. But in the area with which we are concerned, the Mississippian rocks of the Pocono and Mauch Chunk Formations have yielded a few fragmentary plant fossils and the occasional rare amphibian footprint.

The Pennsylvanian period saw the most extensive development of the swampy deltaic environment and the spread of the coal forests associated with it. Indeed, coal deposits of this age are found distributed throughout the northern hemisphere, a fact that may be explained by paleogeographic reconstructions. The Pennsylvanian coal floras of North America and Europe are very similar, and the abundance of the coal deposits indicates a high productivity typical of tropical environments. When the paths of the drifting continents are extrapolated back into the Pennsylvanian, North America and Europe are positioned quite closely to each other and both lie astride the equator.

25. St. Clair, Schuylkill County, Pennsylvania

Lithology -- Dark gray shales, coal.

Fossils -- The typical coal measure flora can be found in the series of strip mines and spoil piles along the road from St. Clair to Mahanoy City. The plant fossils are preserved as impressions, sometimes with carbonaceous or other films coloring the fossils. Common fossils include the lycopods (club-mosses), mostly in two genera, *Sigillaria* and *Lepidodendron*; the latter is found as several different form genera. Thus, the characteristic "scale-tree" pattern of the trunk is known as *Lepidodendron*, the leaf as *Lepidophylloides*, the megaspore as *Lepidocarpon*, and the root as *Stigmaria*. The sphenopsids are represented by *Calamites*; its jointed, lined stems are actually pith impressions. Other sphenopsids found here are *Sphenophyllum*, *Asterophyllites*, and *Annularia*. The sphenopsids' only living relatives are the horsetail rushes. The most abundant true fern at this site is *Pecopteris*. Other fern-type impressions belong to the pteriodosperms (or seed ferns), possible ancestors of the rest of the seed-bearing plants. These more elaborate leaflets include *Neuropteris*, *Mariopteris*, *Alethopteris*, and *Sphenopteris*. Finally, two forms of the extinct gymnosperm *Cordaites* are present; a smaller lowland type that probably grew in a mangrove swamp brackish sort of ecosystem (Gillespie *et al.*, 1978, p. 134); and a larger upland variety that can be found in sandstone blocks at this locality. Faunal remains are rare, but there are reports of insect wings and small crab fossils. Similar areas for finding fossil plants are around Tower City and Scranton-Wilkes Barre.

Age -- Pottsville Group, Lower Pennsylvanian (Westphalian).

Permian

The rocks of this age are missing from the Delaware Valley region. The nearest deposits of Permian strata are the Dunkirk Group in the southwestern corner of Pennsylvania; these beds are terrestrial-aquatic in origin. The lack of Permian rocks in the area covered by this work is attributed to the final tectonic pulse of Appalachian mountain building. Plate tectonic theory indicates that Africa collided with North America during the Permian, and the force of the collision crumpled the older Paleozoic deposits into the synclines and anticlines of the Valley and Ridge province. This suturing of the continents was the last stage in the creation of the supercontinent Pangaea.

Concomitant with the end of the Paleozoic era was a massive extinction episode. Several hypotheses have been set forth to account for the widespread disappearance of many marine invertebrates. Valentine (1973) has proposed that the welding of the continents into one contiguous landmass produced unstable environmental conditions, including greater fluctuations in trophic resources, shrinking of favorable shallow-water habitats, and changes in climate and ocean circulation.

Triassic

The Delaware Valley area was a mountainous region during the Triassic as a result of the tectonic activity associated with the formation of Pangaea. The Lower and Middle Triassic sections are missing from the region because of this activity. During the Upper Triassic, tensional rifting established fault-block valleys along the east coast of North America; the most prominent of these elongated troughs was the Newark Basin, extending from northeastern New Jersey into southeastern Pennsylvania. Sediments from the adjacent mountains poured into the basins, filling the lowland areas with thick sequences of redbeds and dark shales. Analogous situations today would be the East African Rift Valley or the North American Basin and Range province.

During the Permian, reptiles had established themselves as the dominant terrestrial animals. Through the Triassic, the reptiles pursued a variety of evolutionary possibilities. Plant life became somewhat more modern in aspect, with abundant conifers, cycads, ferns, and scouring rushes. The mammal-like reptiles became more sophisticated during the Triassic, so that by the end of the period true mammals appeared. Sea life was relatively limited to a few generalized forms after the Permian extinction, but these diversified through the Triassic.

26. Granton Quarry, North Bergen, Hudson County, New Jersey

Lithology -- Dark gray argillitic shales interbedded with more massive light orange or red sandstones.

Fossils -- Although much reduced from its previous extent, the old Granton Quarry on Route 9 in Bergen is still producing specimens. The most abundant remains here are of the coelacanth fish *Diplurus newarki*. Disassociated bones, scales, and occasionally whole skeletons can be found on the platy layers of the dark gray Lockatong Shale. The shale was deposited in a lacustrine environment; the high sodium content of the shale indicates that at times the lake ecosystem became briny. *Diplurus* is the same kind of fish as the famous "living fossil" coelacanth (*Latimera*) discovered several decades ago in the waters off Madagascar. The coelacanths are relatives of the crossopterygians, which in the Devonian gave rise to the first amphibians. Large concentrations of *Diplurus newarki* were found a number of years ago during excavations for a library at Princeton University. A similar abundance of fish was found in Lockatong shales at Boonton, Morris County, N.J., during excavations for a reservoir; a few of the fossils were *Diplurus*, but most were of the holostean fish *Semionotus*, an ancestor of the modern gar pike. Unfortunately, both of these localities are no longer accessible. Unusual numbers of fish in some of the Lockatong beds require an explanation; it has been proposed that these concentrations reflect the cyclical continental climate prevalent in the area during Newark time. It must be remembered that at this point the east coast of North America was deeply landlocked within the supercontinent Pangaea, far from the moderating meteorological influence of the ocean. During wet spells, extensive lakes spread across the basin floor and the fish population prospered; but the extremes of continental climate also produced arid periods when the lakes contracted and became salty and stagnant, thus causing massive fish mortality. The situation might be compared to the playa lakes of the Basin and Range province. Another curb on the fish population was the predaceous phytosaurs, a specimen of which (*Rutiodon carolinensis*) was found in the Granton quarry in 1963 (Colbert, 1965). The phytosaurs were large crocodile-like relatives of the dinosaurs that flourished during the Triassic only to become extinct in the Lower Jurassic. They lived in much the same sort of environments as modern alligators, in lakes, rivers, and streams. Nearby, in Fort Lee, N.J., a phytosaur (*Rutiodon manhattenens* was found in the Stockton Sandstone below the Palisades Sill back around the turn of the century. The reddish sandstones at the Granton Quarry represent this lithofacies, when the arid part of the climatic cycle prevailed and deposition was primarily by means of river overflow during flooding. Terrestrial plants found in some Lockatong beds indicate a flora of cycads and conifers related to the Chinle Formation of Arizona. Terrestrial animal remains also washed into the lake ecosystem; Colbert (1966) reported a specimen of the unusual gliding lizard *Icarosaurus siefer*i.

Age -- Lockatong Formation, Newark Group, Upper Triassic (Rhaetic).

Jurassic

The Newark Group apparently spans the Triassic-Jurassic boundary. Deposition of redbeds and argillitic shales continued as sediments eroded off the surrounding highlands were brought down into the rift valleys by rivers and streams. Tectonic activity associated with the origin of the Atlantic Ocean produced igneous intrusions (such as the Palisades Sill and Bowman's Hill) and extrusive lava flows (the Watchung Mountains of northeastern New Jersey). Radiometric dating of these rocks, as well as palynological evidence, has established the upper part of the old Brunswick formation as early Jurassic in age.

Life in the Jurassic oceans was diverse, as is amply revealed at localities like Lyme Regis in England. The ammonites in particular underwent rapid evolutionary radiation, producing a variety of species that have served as biostratigraphic markers. Certain reptilian forms went back to the sea, notably the ichthyosaurs and plesiosaurs. On land, the dinosaurs became the dominant animals. By the late Jurassic, the giant dinosaurs of the Morrison fauna appeared. The most interesting newcomer was Archaeopteryx, the first bird.

27. Walter T. Kidde Dinosaur Footprint Quarry, Riker Hill, Roseland, Essex County, New Jersey

Lithology -- Red shale and sandstone with layers of dark argillite; hill capped by basalt.

Fossils -- Over the years, Riker Hill quarry has provided one of the most prolific dinosaur footprint localities in the area. Donated by the former owner to the Essex County Park Commission, the site now bears his name. Access to the quarry is obtained from the Commission and supervised by the staff at the Geological Museum nearby. Taking a camera and plaster-casting materials is advisable; material cannot be removed from the quarry unless it is first approved by the museum staff.

While tracks are common, there are no reptilian bones found here. In the lower part of the Brunswick shales (before the first lava flow of the Watchung Mountains), bone material of a primitive cotylosaur (Hypsognathus fenneri) and a phytosaur (Rutiodon manhattanensis) have been found nearby in Clifton, N.J. A pseudosuchian thecodont, a member of the group ancestral to the dinosaurs, Stegomus arcuatus, has been uncovered at Neshanic Station in Somerset County, N.J., in the lower Brunswick. Correspondingly, fewer dinosaur footprints are present at this lower horizon. After the First Watchung Mountain lava flow, however, tracks become more frequent. Riker Hill is part of the Third Watchung lava flow, thus occupying a position higher up in the Newark Group, correlative to Colbert's (1965) Hook Mountain horizon or to Olsen's (in Jacobs, 1980) Towaco Formation. The dinosaur footprints are usually found on bedding planes that show mud cracks, ripple marks, and/or the impressions of ancient rain drops. These features as well as the red color of the rocks indicate an environment that underwent fluctuations in rainfall as a result of the extremes of weather associated with the prevailing continental climate. Torrential downpours eroded mud from the uplands, and swollen streams deposited loads of sediment over a broad floodplain. Dryer periods baked and oxidized the mud, turning it red and creating the dessication cracks. It was over these mud flats that the dinosaurs wandered, seeking food and water. The next rainy season provided flood-carried sediments that buried the previous surface and created a new muddy surface on which the dinosaurs could leave their imprints. At times, especially during the lower part of the depositional sequence exposed here, the playa lake environment predominated and the dark shales typical of the lacustrine ecosystem were laid down.

At least five types of reptilian tracks are found at this locality. Batracopus is the name given to a tetrapod thecodont that always walked on all fours; possibly it was armored with bony plates. The dinosaurs all could assume a bipedal gait, their distinguishing evolutionary trait. The ichnogenus Grallator is a small, three-toed footprint, probably a carnivore of the coelurosaur group such as Coelophysis (Colbert, 1963). A group of larger (up to 16 inches) prints are assigned the name Eubrontes; these most likely belonged to a large three-toed theropod, an ancestor of the giant meat-eaters that were the terrors of the later Mesozoic. Another track found here is of the type known as Anchisauripus, a three-toed print with well-defined phalangeal pads and a prominent rear-pointing claw-mark that is sometimes preserved. This is interpreted as the footprint of another theropod, although it may also represent a prosauropod, an ancestor of the great "thunder-lizards" such as Camarasaurus or Diplodocus. Finally, there are the tracks of Anomoepus, made by an ornithopod, an herbivorous ornithischian. Sometimes the front limb prints are found in conjunction with the slim hind footprints; the animal apparently could assume either a bipedal or quardipedal pose.

While footprint material is not as definitive of the ancient animals' form as skeletal remains, it can still offer valuable information about the behavior of dinosaurs. Trackways (groups of prints) may show a preferred orientation, suggesting a directed predetermined motion (perhaps migratory in nature). Coombs (1980), among others, has pointed out that some dinosaur footprints found in the Connecticut Valley Jurassic are preserved only as claw and toe marks; similar specimens have been found at the Riker Hill Quarry. Coombs interprets this as evidence for swimming dinosaurs--partially submerged while fording a stream, the animal was buoyant enough to half float and half walk, leaving only more widely spaced toe and claw marks on the stream bed. These types of prints may be more indistinct than the full footprint, but even the complete track may be difficult to perceive; indeed, footprint hunting requires an active imagination. Other dinosaurian ichnofossils found here include tail drag marks and skin imprints on the tracks.

Other fossils found here are variously assigned to insects, small arthropods, or centipedes (these tracks consist of a series of slanted, parallel slash marks). An entire fossil beetle has been recovered from the quarry. Some very small four-toed tracks have been interpreted as amphibian footprints. Another group of fossils seems to be associated with the dark shales laid down when the lake ecosystem covered the area; these include plant fossils (cycads and conifers), fish remains (Semionotus scales and skeletons), and the youngest occurrence of the phytosaurs known from the Newark Group.

There can be little doubt that the dinosaurs represented at this locality were superbly adapted to the continental conditions of Pangaea. Their footprints have also been found at Milford, Whitehall, Avondale, Pompton Falls, New Vernon, and Newark in New Jersey, and at Gwynedd and around York in Pennsylvania. Footprints and trackways from the Connecticut Valley deposits of this age are famous; good areas to observe them are at Rocky Hill, Connecticut, and in the vicinity of Springfield, Massachusetts. But this early Jurassic dinosaurian fauna was far more widespread; because of the vast expanse of Pangaea, the early dinosaurs spread rapidly to many parts of the world, replacing other reptilian types to become the dominant animals for 150 million years. The cosmopolitan nature of the Newark-type fauna is illustrated by discoveries of similar footprints in such widely separated places as South Wales (Tucker and Burchette, 1977) and the central desert of Iran (DeLapparent, 1974). Colbert and Gregory (1957) summarized the fossil succession in the Newark Basin nicely by stating that it "suggests an earlier fauna of phytosaurs and pseudosuchians which was replaced at about the level of the lava flows by a fauna dominated by bipedal dinosaurs."

Age -- Towaco Formation (= portion of upper Brunswick), Newark Group, Lower Jurassic (Liassic).

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